

WASTE-PRODUCT POLLUTION OF BODIES OF WATER
AND WASTE-WATER PURIFICATION

P.E.M. Schneider

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16. Abstract A literature survey is presented on problems of water pollu- tion and self-reclamation methods. It is shown that current flow plays an important role in the turbulent transfer of surface oxygen into deeper water layers and thus to natural waste conversion by living organisms. The amount of oxygen available to living organisms in deep water is strictly dependent on current patterns.			
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This report is a summary of information taken from the literature on the problems of the waste-product pollution of bodies of water and on waste-water purification. The summary has served as one of the bases for the author's lecture on "Currents in nature" during the summer semester of 1973 at the University of Göttingen. The selection has not been made with a view toward completeness, but was intended to give the listeners examples of problems involved in the pollution of bodies of water and the purification of waste water in systemized form, as well as inspiration for formulating their own questions.

Current conditions in bodies of waters play an important role in their self-reclamation. As an example, it might be mentioned that the oxygen dissolved at the surface of waters is transported by turbulent exchange and convection to deeper and/or bottom strata of water -- and thus within the vicinity of a large number of organisms which participate in self-reclamation. The quantity of oxygen available to these organisms is thus a function of current conditions in each case.

This example shows that it is reasonable to devote attention to the currents which occur in nature in their entirety: it might be that the study of currents inherent to bodies of water will offer additional possibilities for the maintenance and improvement of good river and drinking water. Thus plans have been made to produce papers on currents in rivers, lakes and oceans. This report on the literature represents sort of an introduction to this project.

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WASTE-PRODUCT POLLUTION OF BODIES OF WATER AND WASTE-WATER PURIFICATION

P.E.M. Schneider

Introduction

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Water is not a raw material through whose consumption energy is obtained. Water is a substance which passes through physical states. As hot steam, water allows mechanical work to be obtained via the steam engine. As liquid water, it performs mechanical work in the hydroelectric power plant. As ice, it is capable of bursting rock (weathering effect).

In this mechanical work performed by water, its quality plays a subordinate role. In all life processes -- in which water participates -- water quality becomes a decisive variable.

The life processes which take place in the liquid state in animals and man are also codetermined by mental -- and, in the case of man, intellectual -- processes. To this extent, water serves more than life.

"The water budget is disturbed. ... Here and there, the shortage of clean water is beginning to impede economic development. ... Due to the inadequate purification of waste water, the condition of bodies of water has improved only here and there, but not everywhere, in spite of all efforts by communities and industrial enterprises, to say nothing of financial aid from the Lands and the Federal Republic for the construction of water treatment plants; it has deteriorated so much in some cases, however, that many uses are possible today only at unreasonable cost, if at all."

This diagnosis of our waters in the Federal Government's environmental program shows that what were once rivers have become sewers. About half of Germany's large and small rivers are more than just "moderately" polluted. This means that life in the rivers and in the surrounding riverbank landscape is condemned to death if countermeasures are not taken. Through drinking water, which is obtained in part from river water directly, through riverbank filtration, or from ground water supplemented with river water, pollution of the rivers affects all life processes and ultimately acts on man and his mental and intellectual development via his nutrition.

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*Numbers in the margin indicate pagination in the foreign text.

This report discusses problems of waste water pollution, waste water purification, measurement and monitoring systems for water quality, and water transport. It clearly indicates how necessary it is that the self-purifying capacity of bodies of water be maintained.

1. Pollution of Bodies of Water and Drinking Water

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1.1. Overview

Solid, liquid and gaseous wastes are produced in production processes in agriculture, industry, research and educational facilities, public and private households. These facilities are connected with one another via means of transportation. Solid, liquid and gaseous wastes are likewise produced here. Heat produced in the production and transport processes must also be counted among the wastes in this connection.

Waste changes with time under the influence of solids (e.g. weathering by thawing ice), liquids (leaching of undissolved soluble materials by precipitation), gases (e.g. rusting), heat, light (degradation of light-sensitive plastics), chemical reactions and under the action of biological organisms. Substances detrimental to life can be produced in the process. Two extreme phenomena are known: the direct death of river fauna and flora or indirect death through excessive life: the eutrophication of bodies of water. Wastes also exist which are already toxically active as such.

For example, rivers are being polluted with: plastics and suspended materials, detergents, biocides, mineral fertilizers, petroleum products, dissolved heavy metal compounds, with gases which dissolve in raindrops from the polluted air and are carried into the rivers, by cooling water and radioactive waste water.

In addition to heavy metals, for example, drinking water can contain radioactive materials (such noxae can still be detected in New York's drinking water, even though nuclear weapons tests were terminated at the end of 1962), hormones (small quantities of female hormones with contraceptive effects have been detected in London's drinking water), bacteria and viruses (viral diseases which can be transmitted by drinking water include polio and infectious hepatitis), biocides (for example, DDT residues and traces of other chlorinated hydrocarbons and organic phosphorus compounds have been detected in ground water) [31]. Materials in drinking water which can damage the human physiological balance include nitrite, nitrate, sulfate and fluorine. Detergents are also detectable in drinking water. Cell membrane and cytoplasm of unicellular organisms are

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very sensitive to detergents in the simultaneous presence of oil. For example, the reproductive stages of marine plants and animals are influenced negatively by detergents [31]. The germination and development of cress is very strongly inhibited or suppressed by the addition of detergent (one drop) to the germination solution [11]. The eutrophication of bodies of water also affects the drinking water. The flavor and smell of living and dying organisms are due to oils which are produced during development of the organisms and which are distributed in the water as strong-smelling oil globules upon destruction of the organisms. The odor of the organic oils can be intensified by heating, pressure, changes in the density of the water, mechanical motion and chlorination, since odorous materials are then liberated from the cells. Siliceous algae are among such odor-producing organisms, for example. The threshold of human perception of the oil from these algae is at a dilution of 1:2,000,000 [31].

Of the consequences for life which this pollution causes, 15 the following examples have been studied only to a small extent, or not at all:

1. cumulative and potentiating effects of substances simultaneously present;
2. long-term toxic effects of substances;
3. enrichment of noxae via the food chain;
4. carcinogenic substances;
5. possible genetic damage caused by substances.

1.2. Thermal Pollution

At present, the consumption of electricity is doubling every 10 years. Electrical power for the year 2000 is estimated at 350,000 to 400,000 megawatts, i.e. eight times the present level. Forecasts predict that nuclear power plants will produce 30% of the electrical power in about 1980 and 50% in about 1990 [7].

Raw materials must be supplied in order to produce electrical power. Of the energy in this raw material, 40% is delivered as electrical energy by conventional thermal power plants and about 33% by nuclear power plants. The remaining 60% and 67%, respectively, take the form of heat, for whose removal a conventional thermal power plant requires 40 m³ cooling water per second and a nuclear power plant requires 60 m³ per second [7]. This hot water is discharged into bodies of water. The water cools as a 16 function of flow rate, water depth, humidity, wind and evaporation,

air temperature, cloudiness (thermal radiation from the sun is stopped by clouds) and may at times be impossible, depending upon the value of these parameters -- due to the climate and season -- so that water temperature increases on such critical days from nuclear power plant to nuclear power plant. It is therefore necessary to also have cooling towers in power plants to reduce thermal pollution of bodies of water [6]. The operation of cooling towers increases the cost of electrical generation; in addition, the efficiency of the power plant is reduced. They will thus be used only under weather conditions which do not permit further pollution of the rivers.

When cooling towers are employed, only 2% of the above-mentioned quantity of water is required, lost by evaporation and vaporization. Cooling towers thus increase the water vapor content and the temperature of air in the surrounding landscape [7]. Thus fog can form under the right weather conditions.

Consequences of heavy heating of water include the following, for example: Less oxygen is dissolved in the water, i.e. less oxygen is available to microorganisms for the degradation of noxae; the self-reclamation capacity of a section of river decreases; the number of pathogens in the river water increases rapidly. Sultry weather conditions can be produced, since more water than usual evaporates. If drinking water is taken from the river in the form of riverbank filtrate, the heat ends up in the households of drinking water consumers -- the cooling of drinking water is too expensive. The water thereby loses value in terms of refreshment and flavor.

In order to keep these negative influences on bodies of water within certain limits, it has been determined that water temperature may not be more than 3°C higher than the natural temperature (5°C in exceptional cases) after complete mixing of the warmer cooling water with the river water; 28°C may not be exceeded as the maximum temperature in bodies of water (20°C maximum in trout waters) [7].

If the discharge of cooling water is regulated as a function of weather conditions, the natural thermal rhythm of a river is controlled by engineering on the basis of the maximum efficiency of a thermal power plant. The effects which this will have on biological life are unknown. The Erft, a river in the Cologne area, provides an indication in this direction. As the result of the discharge of cooling water, the temperature of the water does not drop below 12°C during the entire year. A red alga is found in the Erft that is native to tropical inland waters of India [31].

1.3. Pollution with Heavy Metals

Heavy metals disturb or prevent the degradation of noxae by microorganisms in biological sewage treatment as the result of the destruction of protein. For example, less than 1% copper, nickel, chromium or zinc in dry sludge has an inhibiting effect on sludge decay [16]. The following were found in the Rhine in 1971: Cu: 8.6 µg/l; As: 3.1 µg/l; Ni: 2.1 µg/l; Pb: 3.2 µg/l; Ag: 2.9 µg/l; Cd: 7.0 µg/l; Hg: 2.4 µg/l; Mo: 7.3 µg/l; Co: 1.3 µg/l; Zn: 26-180 µg/l [17]. As an example of the injurious effects of heavy metals, those of lead, mercury and cadmium will be described [16, 31, 20, 7, 9].

1.3.1. Lead (Pb)

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Lead is used for the sheathing of underground and submarine cables, for battery plates, chemical apparatus, radiation shielding, ammunition production, seals, soldered joints, pipelines and paints. Lead is hazardous for drinking water in the form of tetraethyl lead and tetramethyl lead. In 1960, 258,000 metric tons of lead were processed in the Federal Republic of Germany, and 361,300 tons in 1969. Motor vehicles consume 20%, which thus ends up in the air, where it is inhaled, or goes into water again with the rain. Lead concentrations of 0.01 to 0.03 mg/l are detectable in rainwater, 0.001 to 0.05 mg/l in river water and 0.001 to 0.006 mg/l in ground water, 0.01 to 0.03 mg/l in flowing drinking water, and 0.1 to 0.2 mg/l in pipelines containing drinking water which has stood for a prolonged period. The limit for lead in drinking water has been set at 0.05 mg/l in the U.S. The daily lead intake via food, water and air is 0.3 to 0.6 mg/person. Slightly more than 2 mg in the daily food can cause poisoning. The lead content of the world's oceans is 50 times greater than it was earlier. Annual lead precipitation amounts to at least 500,000 metric tons. In the FRG, 8000 t lead enters the air annually via automobiles and engines. The increase in lead content in the large cities amounts to 15% yearly. Along the Autobahn [superhighway], 50 to 200 mg lead is found per kilogram of vegetable matter, and up to 3000 mg around traffic congestion.

Cases of acute lead poisoning require very large quantities of blood and produce general intoxication symptoms such as vomiting, etc. Lead is a chronically acting toxin if repeatedly taken in in minimum doses. Its effects occur only after a relatively long time, even when the external cause of intoxication has long ceased. The body eliminates lead very slowly. It has been found on the basis of animal experiments that the frequent repetition of minimum lead exposure over a prolonged period is more likely to cause organic injury than quantities of toxin ingested all at once -- "slowly but surely."

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Cases of acute intoxication with large quantities of inorganic lead do not produce clinical pictures of intoxication which would be similar to those of chronic intoxication, either in animal or in human tests. In particular, latent effects in the nervous system have been observed only in cases of chronic intoxication. Nerve diseases have been detected in cases of organic lead poisoning (triethyl lead). On the basis of this fact, we may suspect that chronically ingested inorganic lead is converted into organic (lipoid-soluble) compounds. Lead accumulates in bone and in pathological calcifications and ossifications, as well as gallstones, kidneystones and bronchial calculus. Damage to red blood cells causes anemia and a flat yellowish-gray color in the skin. Other examples given by various authors include damage to the kidneys, temporary or permanent blindness, paralysis symptoms, neuralgias, and lead goiter.

Red deer in the vicinity of lead refineries suffer sacral paralysis (nervous disorder); cattle which have taken in a large amount of lead dust suffer damage to germ cells and spermatazoa, as well as liver cells, e.g. due to the pesticide lead arsenate [16].

1.3.2. Mercury (Hg)

/10

Mercury is used for temperature and pressure measurements in electrical instruments, for mercury vapor lamps (sun lamps) and in alloys (silver amalgam solders). Severe fungal diseases, e.g. of grains, legumes, root crops, potatoes and fruit, are treated with it. Annual world consumption is 9200 tons of mercury. The FRG is one of the most important consumers, using 760 t during 1969. Twenty seven tons were used just to protect plants. Thirty to 200 g Hg is lost in the production of a ton of chlorine (in the FRG, 1964: 100 to 200 g/t chlorine). About 3 t is used annually for forests.

Up to 2.2 ppb (parts per billion) Hg is found in water close to mercury deposits, and 0.01 to 0.07 ppb in ground water. River and seawater contains 0.08 to 0.12 ppb Hg. In cases of heavy pollution, 0.3 ppb or more may be found. Rainwater contains 0.2 to 2.0 ppb Hg. Hg enters the water through industrial waste water and the leaching of sprayed soils. It is deposited on the bottoms of bodies of water, in water plants, microorganisms and fish. Aquatic animals absorb Hg through the entire body surface and with their food. It is found to be enriched in the vitelli of aquatic animals, in shellfish such as mussels and snails. In fish we find high concentrations in the liver, kidneys, lower concentrations in myocardium, spleen, gills, brain, muscle and bone. In Sweden and Finland, fishing is prohibited in many bodies of water due to the high Hg content of fish.

Birds die from seed treated with mercury; the Hg content causes too high an Hg level in the liver and kidney tissues. Studies on the Hg content of bird feathers before application of the seed-treatment solution have indicated a 10- to 20-fold increase in the Hg level (from 1940 to 1950) in Sweden as mercury-bearing sprays were introduced [16]. /11

Examples of symptoms of mercury disorders described by various authors are inflammations of the skin, oral mucous membrane, the kidneys, lymph glands, urinary ducts and the large intestine. Vapors preferentially damage the nervous system (e.g. insomnia, psychological excitability with restlessness, anxiety, depression, motor disorders). Foul-smelling salivation, toothaches and tooth loss, swollen glands around the mouth and neck, ulcers and abscesses in the throat can occur. Similar inflammations occur in the nose, eyes and ears. Bile secretion is disturbed. Since mercury is also eliminated through the milk, it can also be hazardous to nursing infants.

1.3.3. Cadmium

Cadmium is used, among other things, in electroplating, in storage batteries, in dry cells and in paints. World production was 17,000 t in 1969.

Cadmium levels between 0.05 and 0.85 ppm have been detected in beverages. The incubation time for diseases caused by cadmium is up to 30 years for the ingestion of 0.05 ppm.

Cadmium disturbs the body's calcium metabolism; the skeleton shrinks ("itai-itai" disease). Nausea, vomiting with great exhaustion, cold sweating, anxiety also occur at sufficient concentrations.

1.4. Pollution with Carcinogenic Materials [5]

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The development of cancer and the course of the disease is one of the central problems of current research and has not yet been solved. Substances have been discovered in this research which affect the development of cancer and the course of the disease. We shall speak of cancer-promoting substances in this sense below.

Cancer-promoting effects are exhibited by chemical substances, certain strains of viruses (in animals) and types of radiation. The cancer-promoting chemical compounds primarily include polycyclic aromatic hydrocarbons with three to seven

condensed benzene rings, a relatively large number of their alkyl-substituted homologs and several heterocyclic analogs. The above-mentioned substances have cancer-promoting effects at the point where they come in contact with the body. Members of the group of aromatic amines and azo compounds (e.g. β -naphthylamine, 4-dimethylaminoazobenzene = butter yellow) promote cancer in various organs. Alkylated compounds such as mustard gas, ethylenimines and epoxides and several nitrosamines are highly active carcinogens, too. In addition to these organic compounds, the following inorganic substances are also mentioned in the literature as being cancer-promoting: arsenic, beryllium, chromium, zinc, nickel, cobalt and selenium, and the salts of these substances. Carcinogens of vegetable origin include senecio-alkaloids, monocrotaline, carageenine, safrole, tannin, citrus oils, cycasin, and aflatoxin, originating from moulds. Cocarcinogens (substances which themselves do not cause malignant changes in cells but promote a cancer process) include Croton oil, turpentine oil, the basic fraction of creosote oil and certain hormones. Several hundred carcinogenic chemical compounds /13 are known. X-rays, gamma rays and UV rays produce bone and skin carcinomas; radon inhalation produces lung tumors. Burns can also cause skin cancer. In animals, tumors have been found to be caused by viral infection. So far, no evidence exists that human carcinomas are also induced by viral infections.

The widest use is experienced by the polycyclic aromatic substances, most of the active compounds among which are pure laboratory products; many of them also occur naturally, however: 3,4-benzpyrene has been detected in the uppermost strata of earth, in forested regions far from industry and residential areas. Carcinogenic aromatic substances have also been detected in a core taken from the Federsee [Feather Lake] marsh at a depth of 150 m. This 20,000-year-old material could not have been produced by industrial effects. The polycyclic aromatics are synthesized in plants, accumulate upon the natural death of leaves (the benzpyrene content increases by a factor of 4, on the average) and are thereby transferred to the ground. In Lake Constance plankton, 500 μ g carcinogenic aromatics has been found per kg dry material. These aromatics do not originate entirely from the Lake Constance water -- as was demonstrated by growing plankton in carcinogen-free medium. It thus becomes understandable that fat-soluble carcinogenic aromatics have been detected in all vegetable oils and fats, e.g. olive oil, sunflower oil and copra oil. Carcinogenic substances in airborne dust raise the normal natural level of about 100 μ g carcinogens per kilogram dry material to a greater or lesser degree.

In addition to these carcinogens synthesized and enriched in plants, such substances can also be detected in soot, in broiled or smoked foodstuffs, in the aerosols of large cities,

and automobile exhausts. The application of carcinogenic aromatics in the vicinity of the roots of plants sometimes has produced considerable increases in growth. The effectiveness of individual substances corresponded largely to their carcinogenic activity in animal tests. A cancerous degeneration in plants was not observed in these experiments. Thus it may be that the fertilizing action of the clarification sludge is partly due to the high level of carcinogenic aromatics. Fifteen times the quantity of carcinogenic aromatics occurs in clarification sludge as in forest soil. In contrast to enrichment in leaves, we observe no enrichment of administered 3,4-benzpyrenes in fruits and seeds. /14

Cancerogenic aromatics produced technically and in the laboratory and naturally occurring aromatics also end up in bodies of water. Street runoff is particularly polluted, since hot tar pavement yields considerable quantities of carcinogens (road tar contains about 3% 3,4-benzpyrene; bitumen contains less).

In the following, the term carcinogens refers to the total quantity of 1,2-benzanthracene, 10,11-benzofluoranthene, 3,4-benzofluoranthene, 3,4-benzpyrene and indeno(1,2,3-cd)pyrene. The following levels of carcinogens have been found (about 1967):

Ground water	1-10	µg carcinogens/m ³	
Clean to slightly polluted river or seawater	10-50	"	
Moderately polluted surface water	50-100	"	
Highly polluted surface water	100-1000	"	/15
And sewage	up to more than 100,000	"	
In raw sewage of domestic origin	200-6000	"	
In raw sewage from heavy industry	100-600	"	
In mixed raw sewage	1600-130,000	"	
In spring water	7-13	"	
In mixed water from various springs	10-185	"	

Between 1 and 3 μg benzpyrene/l has been found in human urine. This still does not explain the high level of carcinogens in domestic sewage.

Carcinogens have also been found in rivers (about 1969), e.g.:

		μg carcinogen/ m^3	
In the Rhine at Gernsheim	980	"	
Rhine at Oppenheim	2650	"	
Rhine at Rheindürkheim	1610	"	
Rhine at Mainz	730	"	
Main at Obernau	760	"	
Danube at Leipheim	1120	"	
Stockach Aach	1350	"	
Schussen	500	"	
Gersprenz	870	"	<u>/16</u>
Weschnitz	2600	"	
Weil	970	"	

We see that not only large but also small rivers contain considerable quantities of carcinogens. It is thus necessary to eliminate carcinogens which are present when producing drinking water from surface waters. The conventional germ-destroying and preparation methods yield different degrees of purification. Chlorine is least effective. If the carcinogen concentration in untreated water is 100 to 1000 $\mu\text{g}/\text{m}^3$, then all steps in the preparation methods feasible today are necessary (flocculation, ozonization, filtration, activated carbon). If untreated water contains more than 1000 $\mu\text{g}/\text{m}^3$, it is advisable to put the water into drinking water lines only if mixed with ground water after preparation. None of the above-mentioned preparation methods can reduce carcinogen concentration below the natural level in ground water.

2. Sewage Purification

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Since water is a substance which does not increase, but only undergoes changes in physical state within a cycle, the increasing pollution of water in the gaseous, liquid and solid states with wastes represents a reduction in water quality. A result of this is that the quality of drinking water is decreasing with time.

In response to the pollution of water with solid, liquid and gaseous wastes, with heat, with darkness (rivers are being made darker and darker by the increase in their content of suspended matter; a result of this is that too little light is available to water plants for their oxygen-producing assimilation activities), with chemical noxae and dying organisms (as the result of prior eutrophication, which causes mass deaths) when living conditions required by particular organisms are no longer available because of seasonal changes), purification methods have been developed which use solids, which apply the principles of fluid dynamics, and which utilize gases, heat, light, chemical processes and plant and animal organisms to purify sewage.

2.1. Purification with Solids [11, 6, 31, 7]

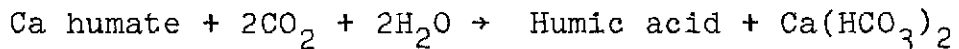
The natural filtering action of the soil should be mentioned as an example of the application of solids to water purification. The effectiveness of filtration is a function of the thickness of the soil stratum, soil composition, and its particle size distribution. A relatively large number of materials are degraded very poorly or not at all as they pass through the ground, or are not adsorbed or absorbed by the soil, in part, and thus end up in the flow of ground water. Passage through the soil also includes riverbank filtration: river water percolates through the river bottom into the ground water of the surrounding landscape and from there is pumped into drinking water lines. The river water loses oxygen in passing through the soil. If there is already a shortage of oxygen (e.g. because of the addition of cooling water or excessive pollution), the oxygen shortage is increased and iron and manganese from the soil go into solution. Odor and taste are changed little by passage through the soil, so bad-tasting river waters retain these properties in modified form. When rivers are heated by cooling water, the heat goes to the consumer with the drinking water, and the latter thus loses its refreshing action. The degradation of organic substances is accomplished by soil organisms. The processes which occur here remain largely unknown. Residues of organic substances are detectable in filtered pure water which are resistant to bacteria. Turbidity is removed by passage through the ground. Pathogens are sometimes rendered noninjurious by other microorganisms. Thus the nature of the surface water used decides the quality of the purified water. /18

The following are examples of unanswered questions:

1. the effect of the type of soil on the penetration depth of substances which endanger or disturb the water supply.
2. how are hazardous substances changed in the ground?

3. how do the results of changes affect the soil and its /19
purifying capacity?

The major portion of solids transported in a river settle out. Part migrates into the riverbed and riverbank and gradually plugs the soil pores, so the rate of riverbank filtration decreases with time. Erosion due to currents extends only a few cm into the ground, so it is not sufficient to prevent stoppage of the lower-lying soil pores. Colloidal materials penetrate deeper into the soil than solids and begin to precipitate as a result of the pH shift to more acidic values and to irreversibly plug the pores. The solubility of alkaline earth humates, salts of humic acid, is a function of pH. Since sufficient CO₂ is available, humic acid is precipitated:



If flow velocity is reduced (e.g. at low water), more materials are deposited, i.e. the production of a riverbank filtrate is endangered. In addition, the concentration of pollutants and the nuisance due to smell and flavor increase as the result of reduced sewage dilution [31].

Riverbank filtration is necessary since the production of ground water is dropping continuously because of the "sealing" of our landscape as it becomes covered with buildings [7]. Lowering of the water table causes desolation of the landscape, i.e. the increasing of foodstuffs production is gradually interrupted by a shortage of water.

Water removal and lowering of the water table so that roots /20 can no longer reach the water results in a pronounced drop off in the quantity of water which evaporates from plants; the vegetation and climate of the landscape thus change, however. Another method uses the high absorption capacity of activated carbon. Materials which produce odor and flavor, organic compounds and detergents are removed as well as possible with its aid, due to the high internal surface area of activated carbon (1000 m²/g or more). The cost of this method is between .10 and .30 DM/m³ waste water [7]. In 1967, 5% of the drinking water in the FRG was treated with activated carbon, while 37% of the drinking water was not treated at all. Until now, 35% of drinking water has been taken from rivers and lakes; in the future, it will be necessary to increase this percentage from surface waters [6].

An additional method, now in development, is reverse osmosis (ultrafiltration). For example, seawater is filtered through suitable membranes which hold back the appropriate ions. Fresh water is obtained in this manner. It is hoped that the

large organic molecules of nondegradable substances in the water can be removed with suitable membranes.

2.2. Purification by Reducing Flow Velocity

Turbulently flowing water is able to keep materials which settle in quiet water in suspension. If flow is slowed, suspended materials settle and can be removed from the water. This is done /21 in the mechanical stage of a clarification plant. The first stage of public sewage treatment in clarification plants begins with the coarse and fine trashracks, which hold back relatively large solids. Gravel, sand, ash, etc. settle in the sand trap which follows. In the preliminary clarification pools which come next, the flow velocity of the waste water is reduced enough that suspended materials settle [11]. The fresh sludge is decomposed by bacteria in septic towers at 37°C. Methane which is produced is used to heat the septic area.

2.3. Purification by Air and Evaporation

A purification method which utilizes air is flotation. Air is first dissolved in the sewage under pressure, which is then relieved. Air bubblets that are generated become attached to the surface of small liquid and solid particles as they rise. The method is particularly suitable for separating suspended matter in the presence of surface-active agents [7].

Polluted river water which enters the vapor phase from the river and ocean is mechanically, chemically and biologically pure. This self-reclamation of the water by evaporation is impaired by air pollution, since rain or falling snow in turn purify the air again. Rain, fog, snow and sleet have the property of easily dissolving gases and mineral and organic compounds. For example, 0.2 to 2.0 ppb mercury, 0.01 to 0.03 mg/l lead, DDT and CO₂ enter the rivers in rainwater. The rise in CO₂ content (particularly of melted snow and ice, which can dissolve much CO₂ from the air because of their low temperature) causes increased weathering of limestone, thereby increasing the lime content of natural and drinking water. /22

2.4. Purification by Combustion

Sewage is burned in muffle furnaces. The water evaporates completely; the contained materials burn at a temperature above 800°C. The cost of the method is more than 10.00 DM/m³. It is used, for example, for waste water from the production of

acrylonitrile. There is also the so-called wet burning process. In it, the liquid to be oxidized is made to react with compressed air in a reaction vessel at 300°C. The gas/water mixture then has its pressure reduced slightly in a separator. Gases thereby separate from the liquid and are led off. It has not yet been possible to achieve complete oxidation of the sewage contents. Biological purification is then also necessary. Costs lie between 3.00 and 15.00 DM/m³ [7, 13].

2.5. Purification with Light and Electricity

Plastics also enter the rivers. These are degraded only with difficulty, or not at all. Plastics with photolabile groups are planned which break down in the light and thereby become biodegradable [7]. A method of removing germs from sewage with ultraviolet rays is being tested [8]. /23

Electrolytic decoloration should also be mentioned here [7]; it is applied to azo dyes. A prerequisite is that the solution have a sufficient salt concentration. The colored waste water passes by the anode and cathode of a cell and is decolorized to a greater or lesser extent, depending upon the length of treatment. The disadvantage is that not all dyes are destroyed and that other organic materials present are oxidized. In a laboratory system, it has been possible to purify water of bacteria, viruses and dirt with a wire network carrying an electric current. The wire grids are supplied with a very slowly pulsating alternating current [32]. Experiments are also being done with underwater pulsed electrical discharges [8].

2.6. Chemical and Magnetic Purification

Sewage is purified chemically, for example, with chemical oxidation using chemicals that leave no toxic compounds behind after reaction. Peracids, sulfuric acid, nitric acid and sodium hypochlorite can be used, for example. The process is expensive. Catalytic oxidation can be done with the catalysts manganese and cobalt, for example. Catalyst losses are sometimes still too high. This causes interference or damage to the receiving ditch of a clarification plant. Ion exchangers consist, among other things, of acid or basic groups which can be exchanged for cations or anions. They are used, for example, in electroplating and in pickling rooms to remove metal ions [7].

Many organic substances, including those in colloidal suspension, are removed from sewage by the addition of iron(II), iron(III) or aluminum salts, followed by hydrolysis (at a suitable pH) or with organic flocculants. So far, this method has not been used much [7]. /24

Sewage which flows through a magnetic field is purified by the coagulation of solid particles, by accelerated sedimentation, by the strong mutual adhesion of particles, and by an increased adsorption rate [15].

2.7. Biological Purification and Quality Classes

2.7.1. Biological Purification [11, 27, 7]

River water and sewage in the air-exposure pools of a clarification plant are purified by the microorganisms present in them under certain conditions. Autotrophic organisms remove the necessary carbon from the CO_2 dissolved in the water and oxidize inorganic substances such as nitrogen, sulfur or iron. Heterotrophic organisms take their carbon from organic matter. Nutritional conditions are shifted in favor of heterotrophic organisms by the degradable organic materials contained in sewages, i.e. the natural equilibrium between heterotrophs and autotrophs is disturbed in that the heterotrophs multiply significantly. Self-reclamation thereby begins. The organic materials are degraded to mineral materials, which are partly incorporated by the organisms. As purity increases, the organism milieu attempts to reestablish an equilibrium between heterotrophs and autotrophs. As the mineral materials increase, the number of autotrophic organisms rises; they are a measure of the trophic state of a body of water. The saprobic level of a body of water is determined from the quantity of heterotrophs present. If the sewage input is massive and persistent, self-reclamation remains at the initial stage of an increase in saprobic level, and the reestablishment of equilibrium is thereby prevented. A body of water in such a state must be considered pathological. /25

The degrading bacteria are arranged in zones with respect to position and time: Carbohydrate-degrading bacteria are at first primarily active, then protein-decaying and -- with sufficient aeration -- nitrifying bacteria in the sewage. Carbohydrates are broken down by groups of organisms which are successively operant. Organic acids are the final products of this metabolism and are broken down either aerobically to CO_2 and water or anaerobically to CO_2 and CH_4 . CH_4 is converted into CO_2 and water by dehydrogenation [27].

Proteins are likewise degraded in stages. The end products of protein degradation include ammonium, hydrogen sulfide and orthophosphate. Various microorganisms oxidize these substances to nitrates, sulfates and phosphates [27].

Lipid degradation produces glycerin and fatty acids by cleavage. Glycerin and then the fatty acids are broken down and converted aerobically into CO_2 and H_2O [27].

The degrading microorganisms are food for higher organisms. /26 Food chains develop through which noxae (e.g. DDT) accumulate in fish and water birds [16].

2.7.2. Quality Classes [27, 11]

The fauna and flora of a body of water are thus a function of its degree of pollution. The zoning of organisms with respect to position and time can thus be used to establish the levels of pollution of flowing bodies of water. Index organisms make it possible to establish four degrees of pollution in flowing waters:

Oligosaprobic zone	Slight pollution	Class I (blue)
β -Mesosaprobic zone	Medium to slight pollution	Class II (green)
α -Mesosaprobic zone	Medium to heavy pollution	Class III (yellow)
Polysaprobic zone	Heaviest pollution	Class IV (red)

2.8. Future Problems

The bacteriology of lakes and rivers is still in its initial stages. It is particularly important with regard to the biochemical alteration of water quality, since the percentage of drinking water taken from surface waters is continually increasing. If an oxygen shortage occurs, for example, nitrates are reduced to ammonium, sulfates to hydrogen sulfide, and iron compounds to soluble iron salts. These materials are hazardous for drinking /28 water. In England, for example, the water became purple in a reservoir that supplied an industrial city and contained chlorinated water of high chemical and bacterial purity. The coloration arose from autotrophic bacteria present in large numbers which could oxidize sulfur. Where this large quantity of sulfur came from could not be determined [31].

"At the end of 1968, the sewage from only 38% of the population was being satisfactorily purified. ... Industry discharges about half of the polluted water produced in its factories via public plants. The other half and most of the drinking water goes directly into bodies of water. In many factories, the waste water is inadequately purified, if at all. ... Various noxae such as heavy metal compounds are not degraded in the purification of industrial waste water" (Federal Government Environmental Program). The pollution of waters will increase.

Purification measures must be tripled if pollution is doubled. As the population increases, more water is consumed per capita. But the waste water is then even more heavily polluted. If more total waste water occurs, proportionately more waste must be removed, and specific costs increase. Forecasts have been made which predict that the financial outlay for cleaning up our waters, i.e. for reducing the pollution present to date to 60% of the current level will have to be increased by a factor of 5 or 6 between now and 1985. Constant prices have been assumed here [6].

3. Parameters for Surface Waters Which Are Being Monitored

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"Water requirements in the FRG will double in the next 30 years, according to estimates by experts. We are still covering drinking water needs largely from the less polluted ground water; in this respect, however, we do not know exactly how much ground water is still unused. More and more water must be taken from polluted rivers and lakes for supplying drinking water in the future -- 35% to date. These bodies of water contain many noxae whose effects have not yet been adequately studied. Overall, the preparation of drinking water will involve increasing costs" (Federal Government Environmental Program). The following is stated regarding measurement and monitoring systems: "The existent measuring and monitoring systems are not adequate to monitor the properties of waters to the extent necessary. We also cannot build a warning system on them to safeguard the water supply" (Federal Government Environmental Program).

The following are the monitoring methods applied:

1. physicochemical methods,
2. bacteriological methods,
3. monitoring of color, turbidity, odor and flavor of the water.

3.1. Physical Methods

/29

3.1.1. Oxygen Content

The oxygen content of pure water decreases with temperature and increases with pressure. In natural bodies of water, oxygen is consumed by the microorganisms which degrade pollution. Assimilating water plants produce oxygen. If sewage pollution becomes excessive, the oxygen content of the waters decreases. Microorganisms die and the water begins to smell bad.

3.1.2. Temperature

The temperature of drinking water should be between 8 and 12°C. Colder water is perceived to be uncomfortable. Gastro-intestinal disorders can be produced at temperatures below 5°C. Water at temperatures above 15 to 17°C is not refreshing [11].

3.1.3. pH

Water with a pH of 7 has a neutral reaction. If pH is below 7, the water has an acid reaction; if above 7, the water has an alkaline reaction. The microorganisms living in the water require a pH range between 6.8 and 7.8. Damage to the bacterial equilibrium can be caused by inadequately neutralized waste water [11].

3.1.4. Electrical Conductivity

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Electrical conductivity is a function of the salt content of a body of water. Monitoring it shows the occurrence of sudden waste-water surges (the salt content of which is higher than that of the natural water).

The instruments for determining the above parameters cost about 45,000 DM.

3.1.5. Radiological Study

The natural radioactivity of water is used for medicinal purposes at mineral springs. Nuclear reactors and research laboratories produce additional radioactive waste water, whose long-lived isotopes (e.g. Sr, Ra, Th) are measured by counting the number of nuclear disintegrations per minute and per unit volume. Radioactive materials can cause damage to gonads.

3.1.6. Several Important Materials Detected Chemically

3.1.6.1. Ammonia

Ammonia results from the reduction of nitrogen compounds and can therefore be considered evidence of water pollution with decaying proteins or decomposing fecal matter. Up to 0.1 mg/l ammonia is found in pure water; between 0.1 and 10 mg/l ammonia in polluted waters. Nitrogen can also be introduced into bodies of water by rainwater [11].

3.1.6.2. Sulfates

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Sulfates are found in clean water in quantities ranging from a few mg/l to 50 mg/l. Sulfate content can amount to several hundred to 1000 mg/l as the result of gypsum which is present because of geological conditions. Mortar, concrete and cement are attacked by high-sulfate water. High sulfate concentrations can be detected in urine and manure liquid. Thus the pollution of water with fecal matter can be detected through sulfates. Excessive concentrations of alkali and magnesium sulfates can cause disorders of the gastrointestinal tract [11].

3.1.6.3. Calcium and Magnesium Salts

The hardness of water is determined by its level of calcium and magnesium salts. Hydrogen carbonates, sulfates and, in considerably smaller quantities, silicates, chlorides, nitrates and phosphates can be detected in natural waters.

Hardness affects the flavor of food and beverages, for example. Hard water (25° dH = German hardness scale) has a laxative effect. Very soft water (4° dH) tastes flat and disrupts tooth and bone development. Deposits in pipelines and vessels and the consumption of soap increase with hardness.

3.1.6.4. Nitrites

Nitrites are rarely found in good water, or at least only in traces (up to about 0.01 mg/l). If nitrites occur in higher concentrations, fecal pollution of the water can be assumed [11]. /32

3.1.6.5. Nitrates

Nitrates are found in small quantities (5 to 10 mg/l) in almost all water. Higher concentrations can be geologically caused (up to 20 mg/l) or be due to pollution with organic or inorganic nitrogen-bearing materials.

Too high a nitrate content in drinking water causes hemoglobin damage in small children, since nitrates are reduced to nitrites by bacteria in the intestine [11].

3.1.6.6. Chlorides

Chloride content is highly dependent upon the geological characteristics of the ground. Water from variegated sandstone

and granite formations contains up to 10 mg/l chlorides. The chloride content of water can rise to several hundreds of milligrams per liter in the vicinity of salt deposits, close to seacoasts, and in Zechstein formations. Human urine contains an average of 10 to 15 g NaCl per day. A chloride level of 30 mg/l or more in water, if not produced by geological conditions, indicates pollution by fecal matter. The self-reclamation of bodies of water does not change chloride content to an appreciable extent [11].

3.2. Bacteriological Methods

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Bacteriologically we determine whether bacteria are present which can cause infectious diseases. The following are determined:

1. total bacteria count per ml;
2. the count of specific bacterial groups (e.g. coliform bacteria);
3. the count of the microorganisms from the intestines of humans, mammals and birds, the presence of which provides an indication of the fecal pollution of water;
4. the count of pathogens (e.g. salmonellae, tuberculous bacteria, cholera vibrios, anthrax bacilli, leptospiras, viruses, etc).

No pathogens are found in protected ground waters. They occur frequently in surface waters. Water must be frequently examined for its bacterial content, since bacteria counts are a function of season, weather conditions and other effects [10].

3.3. Properties of Water Used to Evaluate Its Quality

3.3.1. Color

Substances exist which color water when dissolved in it, making pollution visible.

3.3.2. Turbidity

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Suspended materials make water turbid. The concentration of suspended matter in water can be determined from the intensity of turbidity.

3.3.3. Odor

Drinking water must be free of odor. Most waste waters have specific smells due to inorganic or organic materials contained in them. The human sense of smell is so sensitive that concentrations of substances which are not detectable without enrichment can be discovered by it.

3.3.4. Flavor

The following might be concluded on the basis of flavor, for example:

Flat	soft water
Salty	high salt content
Sour	low pH
Putrid, nauseating	pollutants
Specific flavor	of chlorine, soap, fish, etc. [10]

Waterworks for drinking water are not protected against the sudden occurrence of noxae in untreated water [6]. One method which is therefore used has fish that are in a channel (whose flow is turned on periodically) swim against the current. /35 If substances are present which are injurious to the fish, they die, are dragged against a grating, and trip a warning signal.

4. Water Transport Problems

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4.1. Spring Water Aging

The increase in drinking water consumption makes it necessary to transport water over long-range and connecting lines. Water in pipelines does not have the same quality as water at the source, since it changes with time and with distance from the source. This problem has been studied especially with respect to mineral springs, since they have specially intense therapeutic effects at the point at which they come out of the ground. The curative power of the new water disappears within hours. In the case of many springs, this could be attributed to their decaying radioactivity. But the water from nonradioactive springs also ages and loses its specific curative effects with time.

Dissolved inorganic constituents in the water are suspected of being carriers of the curative effects of mineral springs. Attempts to obtain the inorganic salts unchanged in crystalline form by removing the water in high vacuum at room temperature

and to redissolve them with the addition of the gases originally dissolved yielded mineral waters which did not possess the same therapeutic effects as the original spring water.

These phenomena have been interpreted to the effect that the inorganic salts in the new water are in a labile, active state which converts into a stable, inactive state with time. It has been observed, for example, that a mineral water containing relatively large quantities of iron becomes opalized within a few minutes when exposed to the air in a vessel, and solid, reddish-brown hydrated iron oxide appears. The effectiveness of mineral waters also decreases without such visible outward changes, however. /37

The mineral waters of Vichy exhibit specific catalytic properties in new condition. For example, they decompose hydrogen peroxide into water and oxygen and at the same time exhibit a peroxidal action, e.g. in that they turn a colorless solution of benzidine in hydrogen peroxide an intense blue. These catalytic properties disappear with time.

Laboratory experiments have indicated, for example, that ferrobicarbonate, which occurs in dissolved form in most natural mineral waters and which strongly activates oxygen from the air (i.e. as air oxygen is absorbed, oxidizable compounds such as lactic acid which are present are simultaneously oxidized), loses this capacity within a short time. Iron carbonates in the test tube lose their catalytic properties in just seconds or minutes; in the natural mineral waters, several hours pass before the catalytic properties are lost.

In Franzenbad (Czechoslovakia), it has been found that new water from Glauber spring III is at first crystal clear when placed in an open vessel exposed to air and light but begins to become slightly opalized within several minutes, indicating the beginning of the precipitation of previously dissolved iron salts. Elevated temperature and mixing with air accelerate this process with the simultaneous loss of carbon dioxide. Mineral water in sealed ampules stored in light and in darkness exhibits differences within several minutes. Ampules exposed to daylight exhibit turbidity compared to ampules kept in the dark. The interpretation given for this phenomenon is that mineral water ages in light [3].

The study of the redox potential (rH) of water from the Vichy springs has indicated that the rH is altered, for example, by contact of the exhausted water with air. The interpretation given for this phenomenon is that it is produced by structural changes in the water [33]. /38

Fe_2O_3 has been produced in two different crystal structures (cubic and rhombohedral) in the laboratory. The two substances have completely different chemical and biological reactions. X-ray studies on the substances have indicated the above-mentioned differences in three-dimensional structure. The differences in the substances' behavior have been attributed to this. It is suspected that the substances present in mineral waters are subjected to such three-dimensional structural changes in light and that this causes the loss of catalytic properties of mineral waters [3].

4.2. Dependence of Water Quality upon Pipe Material

A change in water with regard to carcinogenic contents as the result of transport through pipelines has likewise been detected. The levels of carcinogens in the springs studied fell between 7 and 13 $\mu\text{g}/\text{m}^3$, but were 10 to 185 $\mu\text{g}/\text{m}^3$ in mixed water. This increase in the pipeline system probably results from insulating finishes on the insides of the pipelines. In the case studied, bitumen had been used as insulation [5].

Studies with ductile cast pipes with spun-on concrete (GZ) and with PVC pipes in which tap water circulated for up to 10 days, the following was found in comparison to water standing in PVC pipes [8]:

1. KMnO_4 consumption increased in flowing and standing water. The highest increase was observed in water circulating 7 days in GZ pipe. /39
2. When water stands and flows for a relatively long time, the nitrates contained in the water are decomposed.
3. Oxygen loss was greatest in water flowing in the GZ pipes and exceeded 50%.
4. As the result of an increase in alkaline earth ions in the water in GZ pipes, noncarbonate hardness levels increased severalfold. The pipelines were decarbonated by water standing in them for an extended period. Calcium and magnesium salts such as sulfates, silicates, chlorides, carbonates and hydroxides are dissolved in the water out of relatively fresh concrete. The lime / carbonic acid equilibrium is affected by carbonate hydroxides.
5. In all test pipes, the maximum bacteria counts (as for infectious diseases) always occurred after 5 days of flowing or standing. Counts of 46,000 per cm^3 were found in flowing water in the GZ pipe, 80,000 per cm^3 in flowing water in the PVC pipe, and 126,000 per cm^3 in standing water in the PVC pipe. The bacterial counts decreased after 7 or 10 days of flowing or standing, respectively.

6. Good water can be allowed to move or stand in pipelines longer than water of lower quality. The critical dwell time was determined to be 3 to 5 days. After that, water quality drops off.

4.3. Dependence of Water Quality upon Pipe Flow

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Flow in a pipeline is sufficient to kill the highly sensitive, odor-generating plankton organisms which frequently pass through filtration and thus to liberate their odorous substances [31]. The odor of surface waters which are used for water storage thus increases with pipeline length. The preparation processes also cause a further liberation of odorous materials through the destruction of oil droplets in plankton organisms, so residues must always be expected in drinking water.

4.4. Dependence of Water Quality upon Water Mixing

When various waters are mixed, chemical reactions can occur in the pipeline networks which cause an aggressive water. This water attacks the pipelines, causing additional materials to enter the drinking water.

4.5. Deposits in Pipelines

During the course of time, materials deposit on the walls of long-distance water pipelines. This reduces the quantity of water delivered, or operating pressure must be increased. The deposits are a function of flow velocity or Reynolds number. The deposits develop in ripples oriented perpendicular to the principal direction of flow [28].

Summary

/41

The systems of bodies of water are subject to seven categories of pollution: solid, liquid, gaseous, thermal, photo, chemical and biological (1)¹. This sevenfold pollution is combated with solid, liquid, gaseous, thermal, photo, chemical and biological purification methods (2).

Measurement and monitoring systems (3) for surface waters allow only individual materials or groups of materials to be detected in bodies of water. Measurement and monitoring

¹The numerals in parentheses refer to sections in this report.

instruments have not yet been developed for many materials and as-yet unknown compounds.

The known methods of water purification can remove only certain noxae or groups of noxae from waste water. Some of the methods are too expensive to apply, so they can only be employed in special purification plants. Consequences of this are:

1. that the quality of general-purpose and drinking water decreases with time, since only a portion of the noxae are removed from the waters by known purification methods which are applied;
2. that surface waters (rivers, lakes) must also be used as additional water purifiers in the future.

It has been calculated on the basis of measurements that a stretch of the Lower Rhine 100 to 120 km in length has a self-reclamation capacity worth 6 to 8 billion DM. This self-reclamation capacity is reduced by almost 1/3 by noxae that are added to it [6]. /42

A river can get by without technical purification methods such as sewage burning or activated charcoal. Since its self-reclamation capacity is considerable, the question arises as to what factors are operant in a river's self-reclamation. An important factor is current. A study of the significance of current in a river's self-reclamation process can contribute to an understanding of the water transport problems which occur in long-range pipelines and connecting systems [4].

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